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(54) **Fiber-optic endodontic apparatus**

Faseroptische endodontische Vorrichtung

Dispositif endodontique à fibre optique

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EP 0 830 852 B1

Description

[0001] This application is a Divisional Application of EP 94930496.8.

[0002] The invention relates generally to an endodontic apparatus and, to the restoration of a dead or severely decayed tooth by preparing and filling the tooth's root canal with the assistance of optical techniques such as induced fluorescence spectroscopy.

[0003] In particular, the present invention relates to an apparatus for sealing the apex of a root canal in accordance with claim 1. Furthermore, the apparatus of the present invention can also be used for filling a root canal in accordance with claim 2.

[0004] The restoration of a dead or severely decayed tooth requires the tooth's root canal to be cleaned and sealed. The structure of a typical tooth 10 is shown in FIG. 1. The tooth has a crown 12 which extends above the gums 14 and is covered by enamel 16. At the heart: of the tooth is the relatively soft living pulp 18 which includes blood vessels 20 and nerves 22. A hard substance called dentin 24 surrounds the pulp. The tooth also has one or more roots 26 below the gums that fit into sockets in the jawbone 28. Each root is covered by a sensitive, bone like material called the cementum 30. Within each root is a root canal 32. The root canal's structure may have dramatic curvatures and other complex microstructures at almost any position within the root. At the end or apex 34 of the root canal is a small opening, also called the apical foramen, through which the tooth's blood vessels and nerves enter into the root canal.

[0005] The ultimate success of the restoration of a tooth 10 is directly dependent upon the preparation of each root canal 32 and the integrity of the seal of the apex 34. Each root canal must be thoroughly cleaned eliminating tissue remnants, bacteria and antigenic inflammatory chemicals. Inadequate cleaning of the root canal may lead to short-term treatment failure, as well as long-term problems such as persistent inflammation and/or infection. Inadequate sealing of the apex 34 may allow contaminates to enter the root canal which may lead to persistent problems with or even failure of the tooth's restoration. The reintroduction of irritants and the slow dissemination of pathogenic substances through an unsealed opening exit is the most common cause of long-term endodontic failures.

[0006] Also, in conventional endodontic therapy, the root canal 32 must be shaped to allow controlled total filling of the root canal in all dimensions. Since a root canal frequently has an irregular structure, the shaping of the root canal must be carefully performed. As shown in FIGS. 2A and 2B, typical endodontic instruments, such as files 36 and the like, are much harder than the tooth's dentin 24 and tend to go in straight paths when used incorrectly. Such misuse of an endodontic file tends to cause blockages, ledges, via folsas 37, and perforations 38, all of which tend to decrease the chances of a successful tooth restoration. Also, incorrect use of a file may lead to overinstrumentation wherein too much healthy dentin is removed from the tooth which also tends to decrease the chances of a successful restoration.

[0007] As the root canal 32 is cleaned and shaped, the opening at the apex 34 of each root canal must be precisely located and prepared for sealing. The location and preparation of the opening greatly determines the effectiveness of the apical seal.

[0008] The proper preparation of the root canal 32 and location of the apex 34 typically requires a preoperative radiograph to gain insight into the size, shape and location of the root canal. However, the apical third of the root canal is obscured by the jawbone and tends to disappears from view on an x-ray image. The lack of a clear x-ray image of the apical third of the root canal adds to the uncertainty of the root canal's structure and the ultimate success of the restoration since this region of the root canal is where usually most of the root canals structural complexities are found. Certainly, more potential for irreversible damage exists in the apical third of a root canal than in the coronal two-thirds of the canal system. Other methods for determining the length of the tooth such as radiographs, tactile sense, and electronic apex detectors are not always able to precisely detect the location of the opening at the root canal's apex.

[0009] From the discussion above, it should be apparent that there is a need for a root canal explorer that can seal the apex and fill the root canal while being relatively simple and rapid to use, and that: provides lasting results. The present invention addresses these needs.

SUMMARY OF THE INVENTION

[0010] The present invention is embodied in an apparatus for sealing and restoring a tooth's root canal.

[0011] In the present invention, the apparatus includes a plunger, a long hollow tube and an optical fiber. The plunger forces a light cure restorative through the tube to the apex of the root canal. Light is delivered through the optical fiber to activate and cure the light cure restorative, thus sealing the apex of the root canal. Similarly, the apparatus can be adapted to fill the sealed root canal with a light cure restorative.

[0012] Ideally, the entire root canal may be cleaned prepared and filled using the apparatus of the present invention. First, the crown of the tooth is opened and the pulp removed. Next, the entrance at the root canal is located using induced fluorescence spectroscopy. Then root canal is cleaned and shaped. Induced fluorescence spectroscopy is used to determine whether all the infected dentin has been removed, to determine the shape of the root canal, and to prevent damaging and perforating the root canal. Also, the apex is located using induced fluorescence spectroscopy and prepared. A light cure restorative is placed in the opening at the apex and activated with light. After the root canal is

sealed, the remainder of the root canal is filled with light cure restorative.

[0013] Other features and advantages of the present invention should become apparent from the following description of the preferred embodiment, taken in conjunction with the accompanying drawings, which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014]

FIG. 1 illustrates the anatomy of a tooth.

FIG. 2A illustrates a tooth having a via folsa created by an endodontic file.

FIG. 2B illustrates a tooth having a perforated root caused by an endodontic file.

FIG. 3 is a block diagram of an induced fluorescence system for determining the structure of a tooth's root canal.

FIG. 4 is a block diagram of one embodiment of the induced fluorescence system shown in FIG. 3.

FIG. 5 illustrates a fiber-optic apex sealer of the present invention.

FIG. 6 and 7 illustrate a fiber-optic root canal filler of the present invention.

FIG. 8 illustrates the step of curing a light cure restorative in a root canal.

FIG. 9 is a graph of the intensity of fluorescence verses wavelength of light cure restorative before and after curing.

FIG. 10 is a schematic diagram of the concept of a neural network.

[0015] FIG. 4 shows an apparatus not claimed in the present invention, for determining the composition and anatomical boundaries of the root canal 32 of a tooth 10. The light source 42', a suitable HeCd low power laser, directs the excitation light 44' having a wavelength of 442 nanometers towards a suitable dichroic mirror 66. The dichroic mirror, preferably but not necessarily one supplied by CVI of New Mexico, exhibits high reflectance at 442 nanometers and high transmittance at 500 nanometers. The dichroic mirror reflects the excitation light towards a first lens 68.

[0016] The first lens 68 focuses the excitation light 44' into the end of an optical fiber 46' and also collimates the collected return light 48' that is emitted from the optical fiber. The optical fiber has a 400 micrometer core diameter. The distal end of the optical fiber scans the root canal 32 by directing the excitation light in the root canal. The same distal end also collects the return light 48' from the root canal.. The return light passes from the fiber through the first lens, the ultraviolet mirror 66 and a long pass optical filter 70. The long pass optical filter has a cutoff wavelength of 325-345 nanometers to filter scattered or reflected excitation light from the return light. The fluorescent light is focused into a second optical fiber 72 by a second lens 74. The second optical fiber transmits the return light to the entrance of a spectrograph 50'. At the entrance of the spectrograph is a suitable long pass filter, such as the Schott GG475 filter, which further excludes any reflected excitation light from the return light. After the filter is a slit having a slit width of 50 micrometers. The slit is followed by a diffraction grating having 100 grates per millimeter that resolves the return light along an axis.

[0017] Along the axis is positioned a detector 51, preferably a 1024 element linear device array detector (EG&G 1422G). Each element of the detector array corresponds to a spectral wavelength band of the return light. The detector array provides an analog signal that is converted into a digital signal for analysis and processing by an optical multichannel analyzer 52'. The digital signal contains data representing the intensity of light received for each of the spectral wavelengths. The data may also be displayed on the screen of the optical-multichannel analyzer 52' or saved on a data disk. A suitable system which includes both a detector and a multichannel analyzer is an OMA® 4 available from EG&G Princeton Applied Research of Princeton, New Jersey.

[0018] The ratio of the light intensity collected in the several spectral wavelength bands or regions is calculated as discussed above. Using the calculated ratio, the intensity of light within a peak wavelength band is analyzed with the intensity of light with other spectral wavelength bands to identify the portion of the tooth within the root canal thus determining the anatomical boundaries of the tooth.

[0019] In an alternative embodiment of the apparatus according to Fig. 4, the sensor 50 may include an aberration corrected wavelength division multiplexer (WDM) and a 512 x 512 pixel charged-coupled device (CCD) array. The fiber 46 which transmits and couples the return light into an f/2, 15 centimeter focal length aberration corrected WDM and the 512 x 512 pixel CCD array. The WDM's grating will be set at a fixed angle covering a 350 nanometer (300-650 nanometers) spectral range. The light exposure (light intensity x exposure time) for each pixel is digitized on a linear scale from 0 to 2^{14} (16,384). The array may be liquid nitrogen cooled array which results in a substantial reduction of background noise signals. In addition, since the background noise signals are almost uniformly distributed across the array, the average noise signal may be subtracted from the fluorescence signal from each detector element of

the array. A suitable sensor is the 1530-CUV cryogenically cooled CCD detector available from EG&G Princeton Applied Research of Princeton, New Jersey.

[0020] In another alternative embodiment, the sensor 50 may include a photodetector (PD) array having a built-in thermo-electric cooler (TEC). The TEC cooled array detector operates with lower noise levels than room temperature array detectors. A suitable TEC cooled array is the 1530-PUV thermoelectrically cooled CCD detector available from EG&G Princeton Applied Research of Princeton, New Jersey.

[0021] In a further embodiment, the processor 52' may include an artificial neural network as shown in FIG. 10. 5 The artificial neural network consists of layers of interconnected processors (neurons) 106. The spectral data from the sensor 50' is input at the input neuron layer 108. Preferably, each of the wavelength bands discussed is divided into 10 smaller bands or windows. The input neuron layer has sufficient inputs to receive the data for each wavelength band of interest. The neural network performs a nonlinear transformation on the input data and produces its result at the output neuron layer 110. Neural network has great flexibility in that it can be taught to transform the spectral data (input neuron layer) into an output (output neuron layer) that automatically and uniquely identifies the components of the tooth with relatively very high sensitivity (one to two orders higher than the conventional detection limit), high speed (a fraction of a second for identifying one spectrum), and high reliability (confidence level being indicated by neural network output). The software implementing the neuron network is preferably the substance identification "Neural Network" software package from Physical Optics Corporation of Torrance, California. The neural network operations and decision making may be performed on an IBM compatible personal computer.

[0022] After cleaning the root canal 32, the apex 34 is sealed with light cure restoratives as shown in FIG. 5. The apex sealing apparatus 96 includes a plunger 98, a tube 100 and an optical fiber 102. The tube and the optical fiber extend to the apex of the root canal. The plunger is used to force light cure restorative through the tube. The light cure restorative is deposited at the apex of the root canal. The optical fiber delivers light to the apex to activate the light cure restorative.

[0023] After the apex 34 has been sealed, the entire root canal 32 is filled with light cure restorative as shown in FIG. 6. The filling instrument 104 is shown in FIG. 7 and is similar in construction to the apex sealing apparatus 96, but the tube 100' is not required to extend completely to the apex of the tooth 10.

[0024] The fiber-optic induced fluorescence system is also suitable for detection of whether the light cure restorative 106 has actually cured. As shown in FIGS. 8 and 9, the fluorescence signal received from the light cure restorative, such as Silex Plus 3M®, before it is light activated 108 is much larger than the signal received after the restorative is activated by blue light and the compound polymerizes 110. This intensity decrease in a predetermined wavelength range, such as 500 to 540 nanometers, provides a feedback mechanism to control the root canal sealing and filling process and ensure that the sealing compound is properly cured. The curing process typically takes 1 to 5 minutes after the compound has been light activated.

[0025] A wide variety of fibers can be used in the present invention. The ultraviolet and visible light is readily transmitted through polymethylmethacrylate (PMMA0), polystyrene (PS) and silica-core fibers coated with silica, plastic clad silica and metal coated silica. Near-infrared light is readily transmitted through silica fibers. Mid-infrared (Tm:YAG,Ho:YAG) light is readily transmitted through low OH anhydroguide G Silica fiber. Erbium YAG or Er:YSGG (3,100 nanometers) light is readily transmitted through a zirconium fluoride fiber, however, flour is toxic.

[0026] If desired, the fiber-optic root canal tools discussed above may also be used to supplement conventional endodontic techniques of pre-procedure radiographs, tactile perception, average tooth length charts, etc. Thus, the dentist can choose the extent to which the fiber-optic tools are utilized.

[0027] From the foregoing, it will be appreciated that the endodontic tools discussed above tend to reduce the number of x-rays otherwise needed and used in conjunction with conventional instrument methods according to the skill and resources of the individual dentist. The endodontic tools clean and prepare the canal, thereby tending to reduce via folsas, and to minimize the dangers of broken instruments. The tools can establish the working length of the tooth, and locate the apex and seal the apex using light cure restoratives and/or high heat generated by light and fill the root canal with light cure restoratives. The tools also can eliminate pulp and pulp stones, and can cut, widen, and coagulate using infrared lasers through these same fiber-optic headpieces. In addition, the endodontic tools discussed above provide relatively instantaneous determination of the composition of the root canal without the processing delays associated with x-rays, etc.

Claims

1. Apparatus for sealing the apex (34) of a root canal (32) with a light cure restorative (106), comprising:

    a long hollow tube (100) sized to fit within the root canal (32) and to extend to the apex of the root canal (32);

    a plunger (98) for forcing the light cure restorative (106) through the tube (100) and into the apex (34) of the root canal (32); and

    an optical fiber (46; 88; 102) sized to extend to

the apex of the root canal (32) for delivering light to the apex (34) of the root canal (32) to cure the light cure restorative (106).

2. Apparatus for filling a root canal (32) with a light cure restorative (106), comprising:

   a long hollow tube (100') sized to fit within the root canal (32); and

   a plunger (98') for forcing a light cure restorative (106) through the tube (100) and into the root canal (32); and

   an optical fiber (46; 88; 102') for delivering light inside the root canal (32) to cure the light cure polymer (106).

Patentansprüche

1. Vorrichtung zum Verschließen des Endes (34) eines Wurzelkanals (32) mit einem lichtaushärtenden Aufbaumaterial, mit:

   einer langen hohlen Röhre (100), welche so bemessen ist, daß sie in den Wurzelkanal (32) paßt und sich zu dem Ende des Wurzelkanals (32) erstreckt;

   einem Kolben (98) zum Zwangseinbringen des lichtaushärtenden Aufbaumaterials (106) durch die Röhre (100) und in das Ende (34) des Wurzelkanals (32); und

   einer optischen Faser (46;88;102), welche so bemessen ist, daß sie sich zu dem Ende des Wurzelkanals (32) erstreckt und zur Zufuhr von Licht zu dem Ende (34) des Wurzelkanals (32), um das lichtaushärtende Aufbaumaterial (106) auszuhärten.

2. Vorrichtung zur Füllung eines Wurzelkanals (32) mit einem lichtaushärtenden Aufbaumaterial (106), mit:

   einer langen höhlen Röhre (100'), welche so bemessen ist, daß sie in den Wurzelkanal (32) paßt; und

   einem Kolben (98') zum Zwangseinbringen eines lichtaushärtenden Aufbaumaterials (106) durch die Röhre (100) und in den Wurzelkanal (32); und

   einer optischen Faser (46;88;102') zur Zufuhr von Licht in das Innere des Wurzelkanals (32), um das lichtaushärtende Polymer (106) auszuhärten.

Revendications

1. Appareil pour obturer le sommet (34) d'un canal de racine (32) avec un reconstituant photo-durcissable (106), comprenant :

   un long tube creux (100) dimensionné de manière à s'ajuster à l'intérieur du canal de racine (32) et à s'étendre jusqu'au sommet du canal de racine (32) ;
   un plongeur (98) pour pousser de force le reconstituant photo-durcissable (106) à travers le tube (100) et dans le sommet (34) du canal de racine (32) ; et
   une fibre optique (46 ; 88 ; 102) dimensionnée de manière à s'étendre jusqu'au sommet du canal de racine (32) pour amener la lumière au sommet (34) du canal de racine (32) afin de durcir le reconstituant photo-durcissable (106).

2. Appareil pour remplir un canal de racine (32) avec un reconstituant photo-durcissable (106), comprenant :

   un long tube creux (100') dimensionné de manière à s'ajuster à l'intérieur du canal de racine (32) ;
   un plongeur (98') pour pousser de force un reconstituant photo-durcissable (106) dans le tube (100') et dans le canal de racine (32) ; et
   une fibre optique (46 ; 88 ; 102') pour amener la lumière à l'intérieur du canal de racine (32) afin de durcir le polymère photo-durcissable (106).

FIG. 1
PRIOR ART

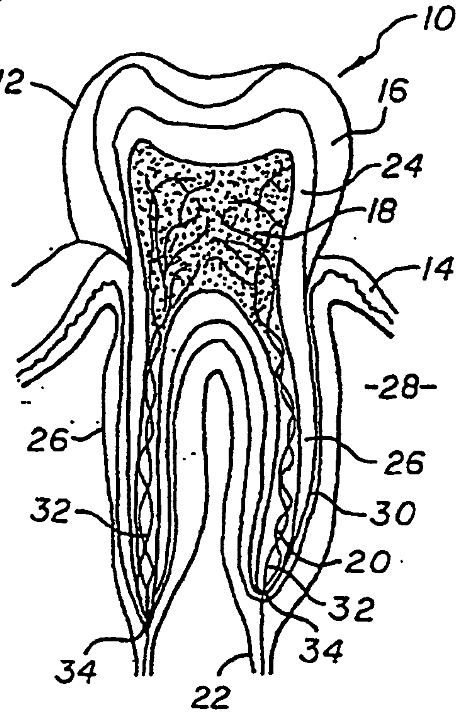


FIG. 2A
PRIOR ART

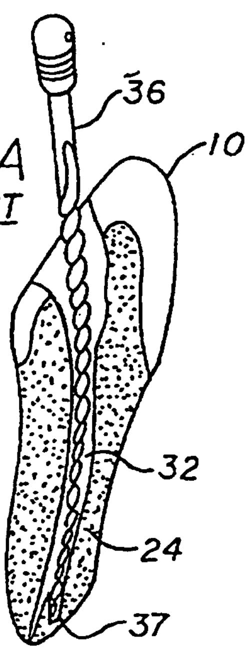


FIG. 2B
PRIOR ART

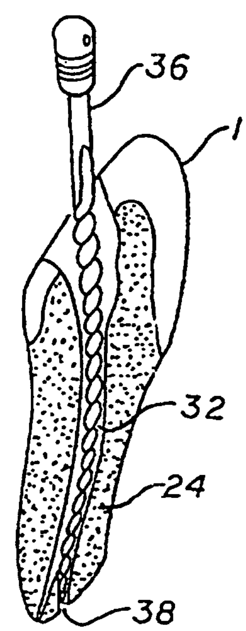
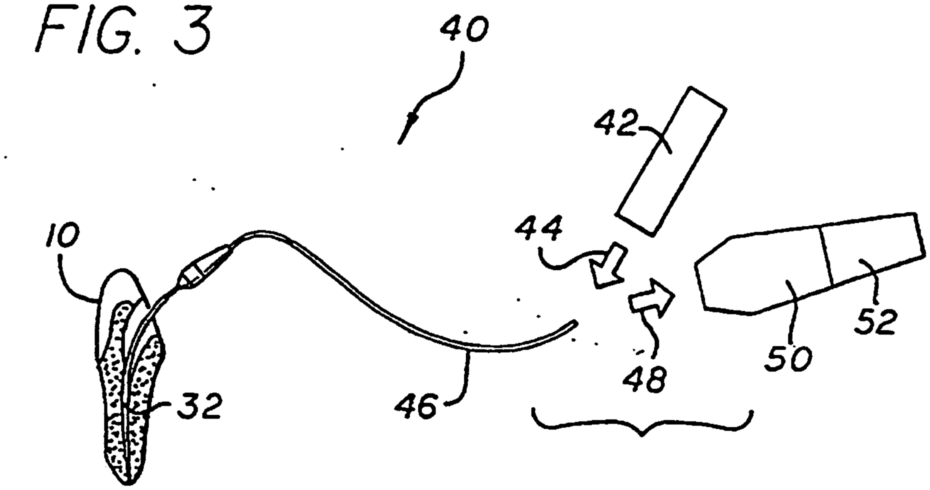


FIG. 3



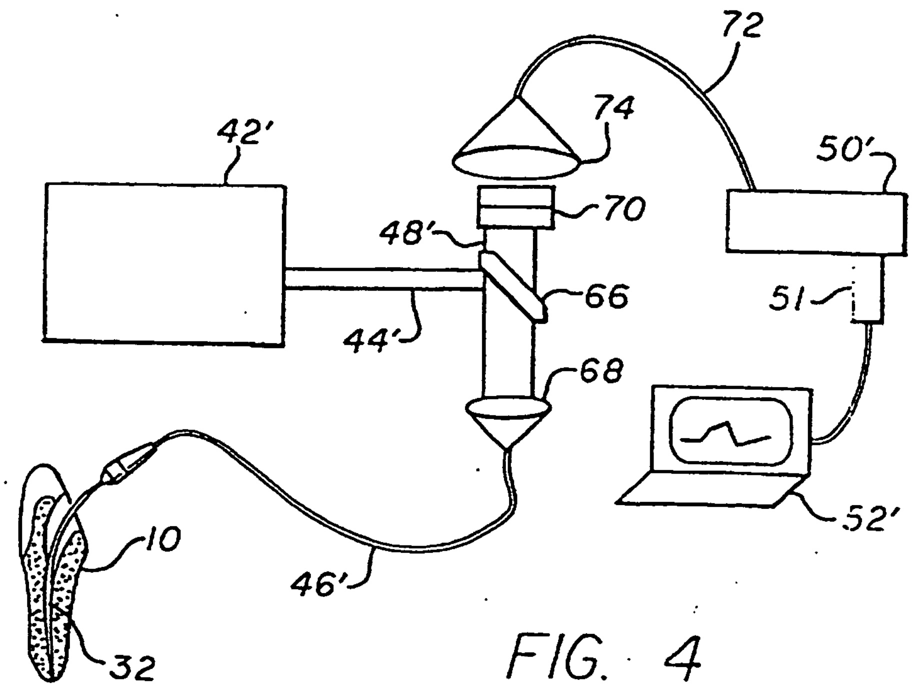


FIG. 4

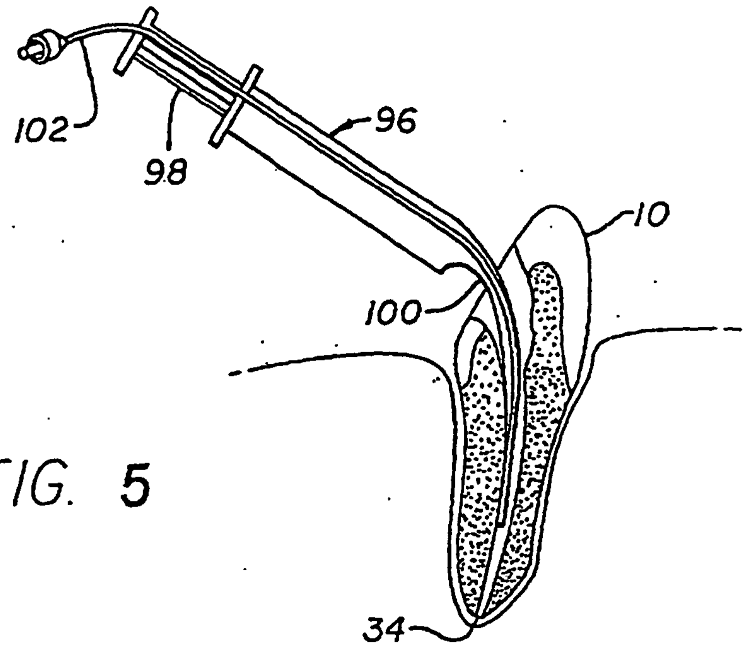


FIG. 5

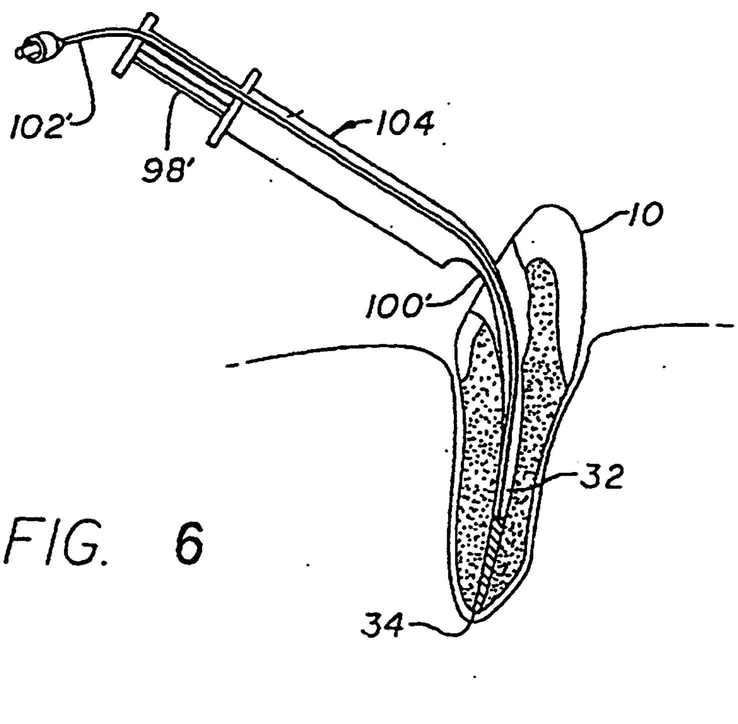
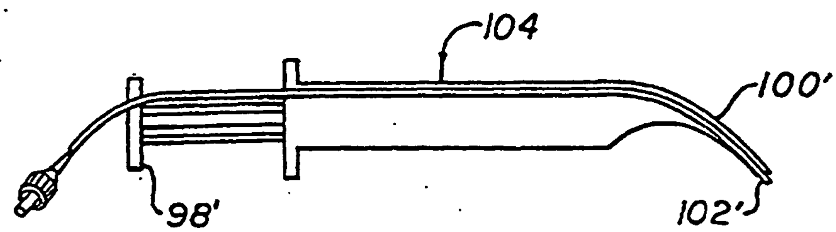


FIG. 6

FIG. 7



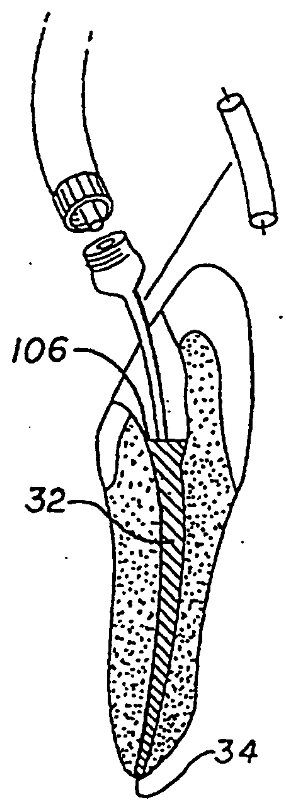


FIG. 8

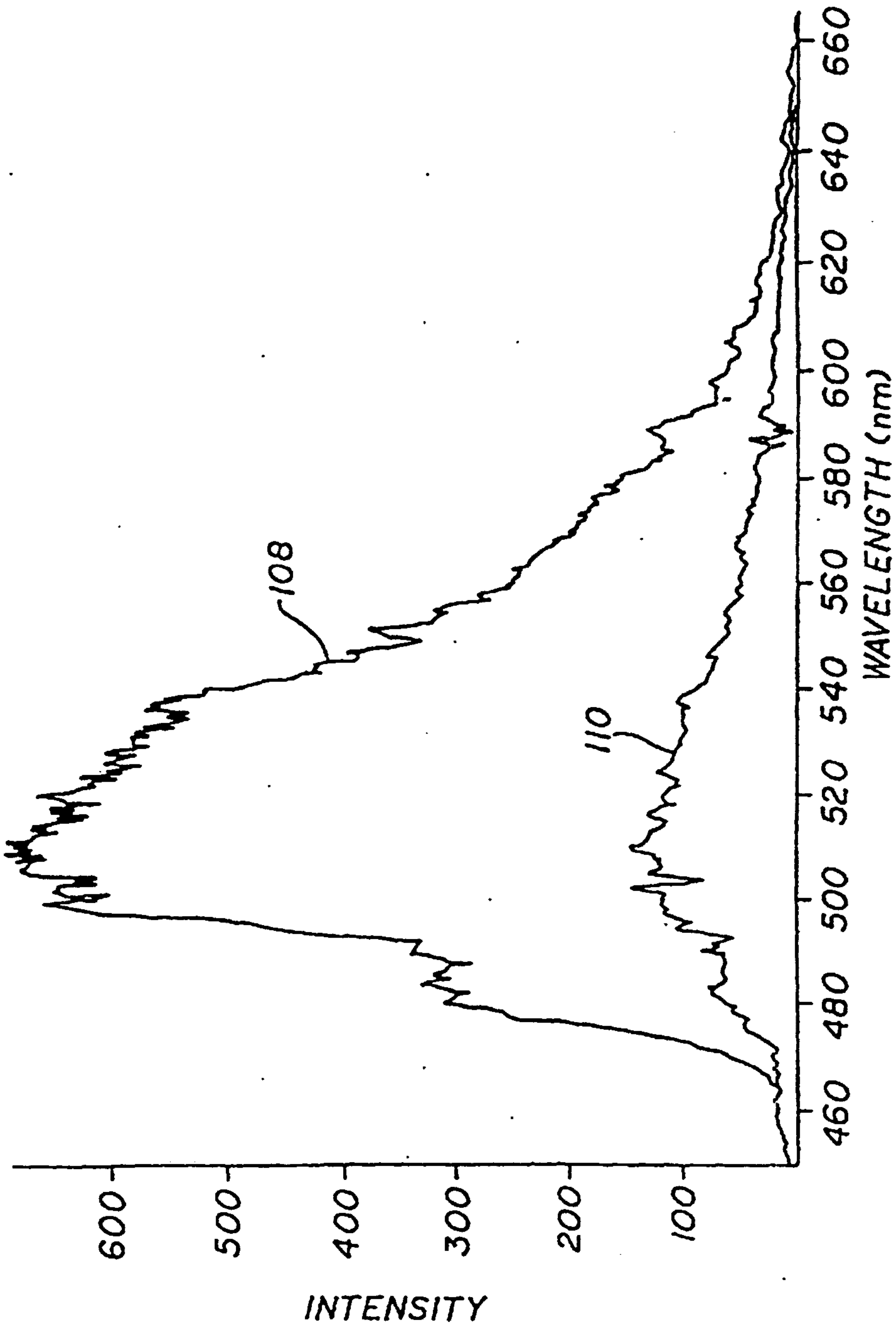

108
110
INTENSITY
100
200
300
400
500
600
WAVELENGTH (nm)
460
480
500
520
540
560
580
600
620
640
660

FIG. 9

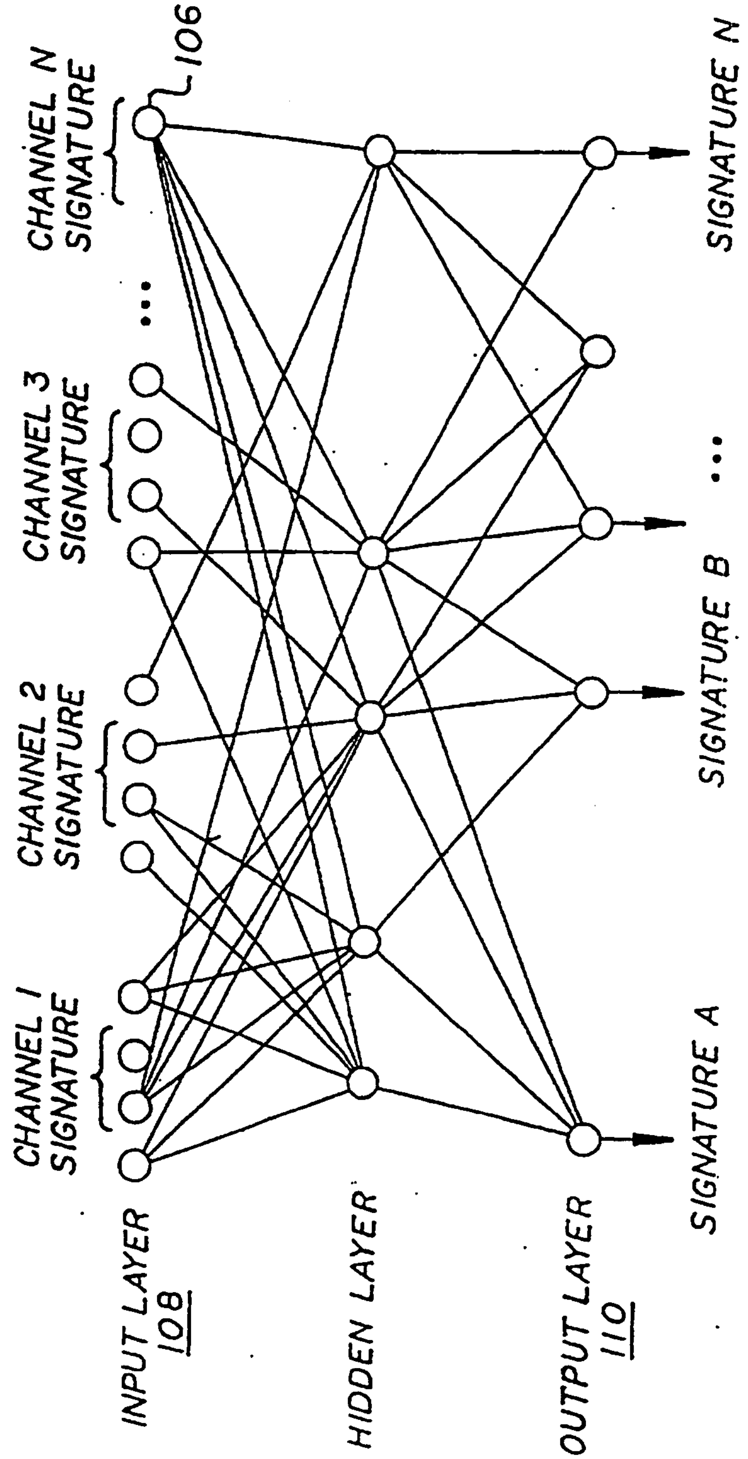

CHANNEL 1 SIGNATURE
CHANNEL 2 SIGNATURE
CHANNEL 3 SIGNATURE
CHANNEL N SIGNATURE
106
INPUT LAYER 108
HIDDEN LAYER
OUTPUT LAYER 110
SIGNATURE A
SIGNATURE B
SIGNATURE N

FIG. 10